ECONOMIC BENEFITS OF SYSTEMATIC ROOF BOLTING IN ZEIGLER NO. 3 MINE, BELL & ZOLLER COAL & MINING CO., WILLIAMSON COUNTY, ILL.

By L. W. Kelly

* * * * * * * * * * **Information Circular 7633**

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SUMMARY

The purpose of this paper is to indicate some of the benefits that have been derived in the Zeigler No. 3 mine by using roof bolts under extremely adverse roof conditions, with the thought that much better results could be obtained in other mines with more normal roof conditions by applying some of the practices that were developed in this mine. Some of the benefits that have been obtained in this mine, which will be shown in this paper, are:

1. Increased tonnage per man-shift at the face when roof bolts are used, as compared to the tonnage under similar conditions when conventional timbering methods were used.

2. Increased efficiency of roof bolting by giving the foremen a definite plan to follow.

3. Reduction in delays caused by failures of the trailing cables of loading, mining, and drilling machines.

4. Reduction in the number of accidents after roof bolting was adopted.

Inasmuch as the success that followed roof bolting in this mine was obtained under one of the most treacherous roofs in the Middle West, it is reasonable to suppose that correspondingly better results could be obtained under more favorable roof conditions by using the same procedure.

INTRODUCTION

Since the advent of the first systematic installation of roof bolts in coal mines in 1947, their general adoption and use have become the most spectacular development in coal-mining history. The use of roof bolts has expanded so rapidly and under so many different conditions that it has been impossible to record and tabulate more than a few facts regarding the actual economic benefits realized. Many of the installations were started with only fragmentary knowledge of the requirements; but, as they were in most instances immediately successful, the original methods were continued. Hence, there was comparatively little experimentation to determine whether or not some variation of the system in use could be adopted that would result in greater efficiency insofar as cost was concerned.

When considering the data presented in this paper, it must be realized that it is questionable if this mine could be operated economically if roof bolting had not been adopted. All of the conventional methods of timbering had been used, but it was impossible to carry on the normal cycle of cutting, blasting, and loading without excessive delays, due to placement of timbers. As a result, the mining cost was considered by the management to be above the

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economic limit, and some radical improvement had to be made. Roof bolting proved to be the solution.

The mine was opened in May 1948 and operated under extremely adverse roof conditions for approximately 2 years; but, with the successful adoption of roof bolting, control of this roof was possible to such an extent that the mine is now producing 5,000 tons of coal a day.

Many mines that have adopted roof bolting as a standard operation in their mining cycle are not deriving the maximum benefits from their use. While the primary function of roof bolts is to support the overlying strata, adaptations of the roof-bolting principle often can be utilized to advantage in other phases of the mining cycle. One example of this will be shown in this paper.

ACKNOWLEDGMENTS

This circular was made possible by the generous cooperation of Ernest Prudent, general superintendent, William Guiney, superintendent, and John Lyons, safety engineer and photographer, Bell & Zoller Coal & Mining Co.. The information and time generously given are acknowledged gratefully.

GENERAL INFORMATION

Zeigler No. 3 mine is in Williamson County, Ill., 3 miles south of the town of Zeigler. The mine was opened in May 1948 by two circular, concrete- and steel-lined slopes. The main slope, 528 feet long and equipped with a 36-inch belt and a steel stairway, serves as the intake airway. The material slope, 320 feet long and equipped with a track, is the return airway. The slopes are 500 feet apart. The mine is developed in the Illinois No. 6 coal bed, which averages 108 inches in thickness, is faulted extensively, and is broken by many slips, rolls, horsebacks, and clay veins. The maximum cover is 160 feet, and the top 110 feet of this cover consists of sand, top soil, and water. The roof conditions are extremely poor and are considered by many to be the worst in Illinois. The room-and-pillar method of mining is followed, and the pillars are not extracted. The main entries are driven in sets of six, and the cross entries are driven in sets of four. All of the entries are 14 feet wide at the bottom of the coal bed, 12 feet wide at the top, and are driven on 34-foot centers. The rooms are driven 24 feet wide on 50-foot centers. A total of 294 men is employed, and of this number 275 work underground. The average daily production is approximately 5,000 tons of coal, all loaded mechanically. Loading machines load the coal into shuttle cars, and it is transferred to drop-bottom mine cars. The cars are transported to a bin at the slope bottom, and a belt conveyor takes the coal to the surface preparation plant. The mine is ventilated with an exhausting fan, which ventilates the haulage roads with intake air and the seals with return air. The life of the mine is estimated to be 14 years at the present rate of production.

CHARACTER OF ROOF AND TIMBERING METHODS

The immediate roof consists of 28 feet of soft, white, weak shale that disintegrates rapidly when wet. Pieces of the roof shale that have been taken

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out of the mine and allowed to stand in the weather soon became mud. This shale is not laminated or stratified and has no consistent lines of cleavage. The main roof consists of approximately 10 feet of well-indurated black shale.

Unsupported, immediate roof falls to the black shale. The first failure occurs in the form of an arch with a maximum thickness of approximately 3 feet in the center, decreasing to zero at the ribs. If this arch is not supported, the remainder of the 28 feet of shale will slough to the black shale. The homogeneity of the immediate roof is destroyed by extensive faulting and the prevalence of slips, rolls, horsebacks, and clay veins. Top coal is not left because its value as a roof support in the southern Illinois field is doubtful. It is apparent in this mine that the benefits derived from the additional headroom and additional coal obtained by taking down the top coal outweigh any advantages that might be gained by leaving it in place. The floor consists of soft fire clay, which disintegrates and turns to mud when exposed to the mine air.

The roof in the main haulage roads and in some of the sections is supported by conventional timbering. The pin timbering method is used, which consists of inserting short pieces of steel rail into holes drilled in the ribs near the roof. Rails on these pins support treated wooden cross bars set on 3- or 4-foot centers. In the rooms and cross entries where roof bolts are not used, the roof is supported with wooden cross bars.

HISTORY OF ROOF BOLTING IN ZEIGLER NO. 3 MINE

When the slopes had reached the coal and the entries were started, it was realized that the roof in this mine would be difficult to support. The weak roof interspersed with faults, slips, and clay veins and the presence of water made roof support a major problem from the outset. It was extremely difficult to support the roof with the degree of permanence required under modern mechanical-mining methods with ordinary timbering, and the time consumed in timbering the working places after the coal had been loaded out slowed the cutting and subsequent mining operations so much that the production per man-shift was very low. Studies were made of the roof falls for about 2 years, and the decision was made to try roof bolting. On the basis of observation of falls over a period of 2 years, supplemented by calculations involving the weight of rock and the ultimate tensile strength of different sizes of steel bolts, the decision was made to use two 5-foot, 3/4-inch bolts in the entries. Knowing that the immediate roof had no computable strength and probably would break between the bolts if conventional 8- by 8-inch steel plates were used alone, it was decided to have the bolts support a 1-1/2- by 7- by 66-inch oak plank by drilling a hole through the plank 6 inches from each end. This would leave 39 inches of roof unsupported from each end of the plank to the rib. These sets (bolts and plank) were to be spaced 4 feet apart along the entry. The foregoing was almost entirely arbitrary but was the basis for the experimental installation.

The first bolts that were tried were wedge-type bolts, but these pulled out when the nut was tightened, as the shale was too plastic to maintain the wedge seat. Next, a popular brand of expansion shell was tried, but this was too weak to withstand the necessary load and either broke or pulled out of the

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hole. Then, some double-expansion shells were prepared in the mine shop and tested. At first they appeared to be successful. This shell is a unit that flares each way from the center and contains two plugs, one of which (the upper) is threaded. The bolts used with these shells were 3/4-inch in diameter and 5 feet in length and were installed in the manner previously described. These shells were used for several months; and, while they were not completely satisfactory, were so successful that the officials knew they could work the mine economically by using them in conjunction with occasional timbers. Recently a new type of expansion shell was obtained that has a square plug, which, when expanded in the hole, forces four flat faces of the shell into contact with the rock. This new shell has been so successful that the double-tapered shell is being discontinued. At present, 13,600 linear feet of entry roof and 16,000 linear feet of room roof have been supported.

EQUIPMENT

After the advantages of roof bolting were recognized, it was evident that a quick method of installing the bolts was necessary; and, with a surplus of No. 474 Chicago Pneumatic coal drills on hand, it was decided to use them, as they had given very good service before. A Model T.J.G. Baker tractor was stripped of its batteries, motor, and control; and, with some modification of the frame, two drills were mounted, one on each side of the frame just behind the front wheels. The drills were mounted on regular turntables so that they could be tilted when auger changes or extensions were made. They were fixed to posts, which were pivoted to allow either drill to swing to the extreme outside or back of the truck. A simple latch locked the drills in the vertical position when tilted back for drilling. A board-jack, using standard equipment, was midway between the drills to hold the board in place until the bolts were installed. This also affords protection from falling roof when the two men are drilling holes and installing bolts. This is shown in figures 1 and 2. Each drill is equipped with a 20-ampere fuse, which is enough for drilling and for tightening the bolts.

A Jeffrey 7-1/2-horsepower, L-38-B conveyor motor was substituted for the battery-powered motor on the truck and connected to the differential by means of a V-belt drive, which gave the tractor a speed of 2-1/2 miles an hour. A Jeffrey class 21 starting box was used to control the motor. Three class 21 Jeffrey headlights were used, one forward, one rear, and one tilted to light the roof where the bolts were being installed. Three hundred feet of No. 2 twin parallel trailing cable is used. It consists of spliced and vulcanized sections of old cables and offers good mechanical protection as it is dragged by the tractor.

The bolts are tightened with the drill motor through a friction-clutch adapter used with the socket to tighten the nut or bolt, whichever type is used. The friction band in this clutch is standard equipment on the No. 580 drill. It is adjusted to provide the proper torque to tighten the bolts and is checked every 7 days with a torque meter and the adjustment locked so that it cannot be tampered with. A spring-loaded extension between the clutch and the socket keeps the socket on the nut as it is screwed up on the bolt. These features are shown in figures 3 and 4.

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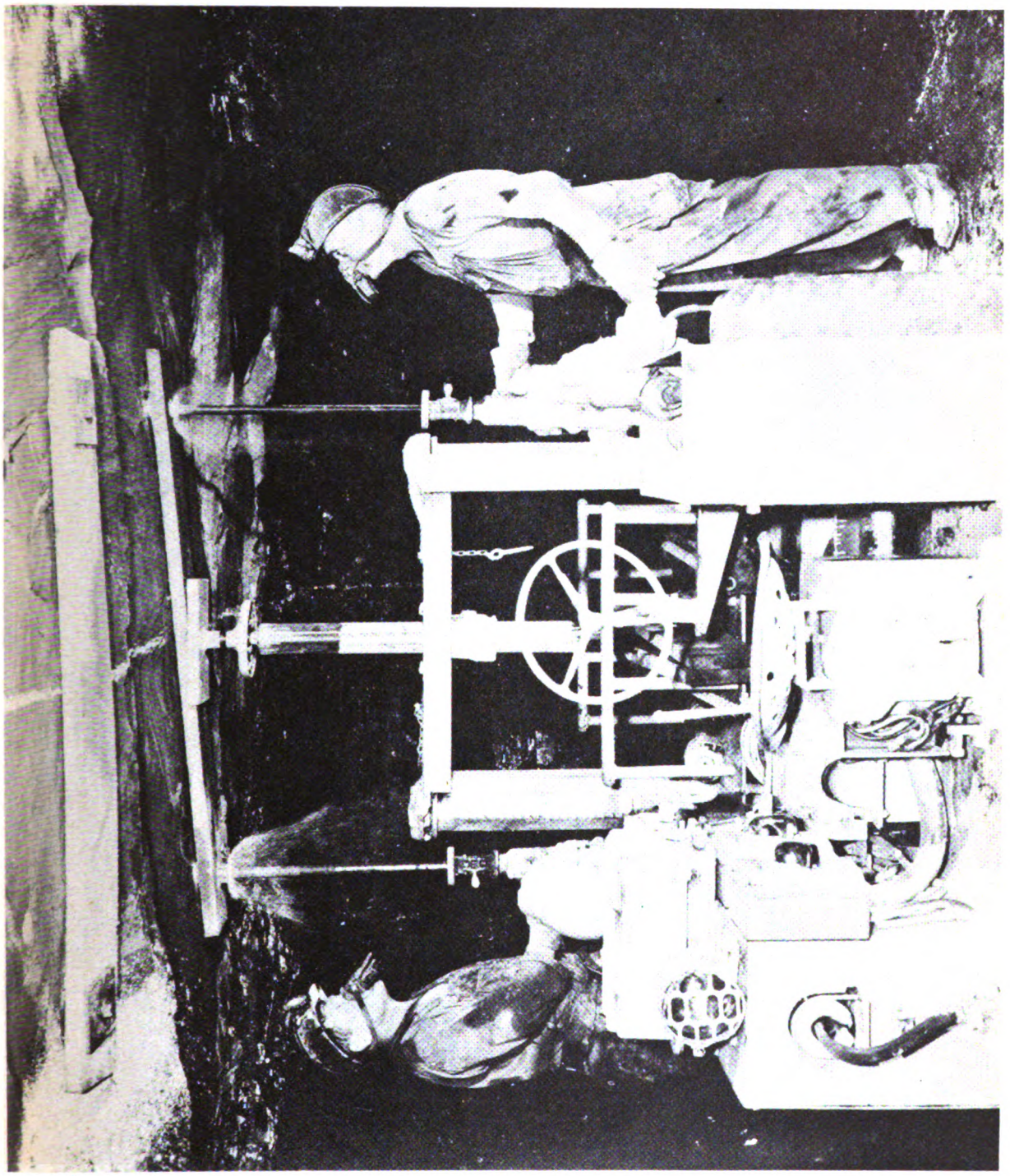

Figure 1. - Roof-bolt machine in operation.

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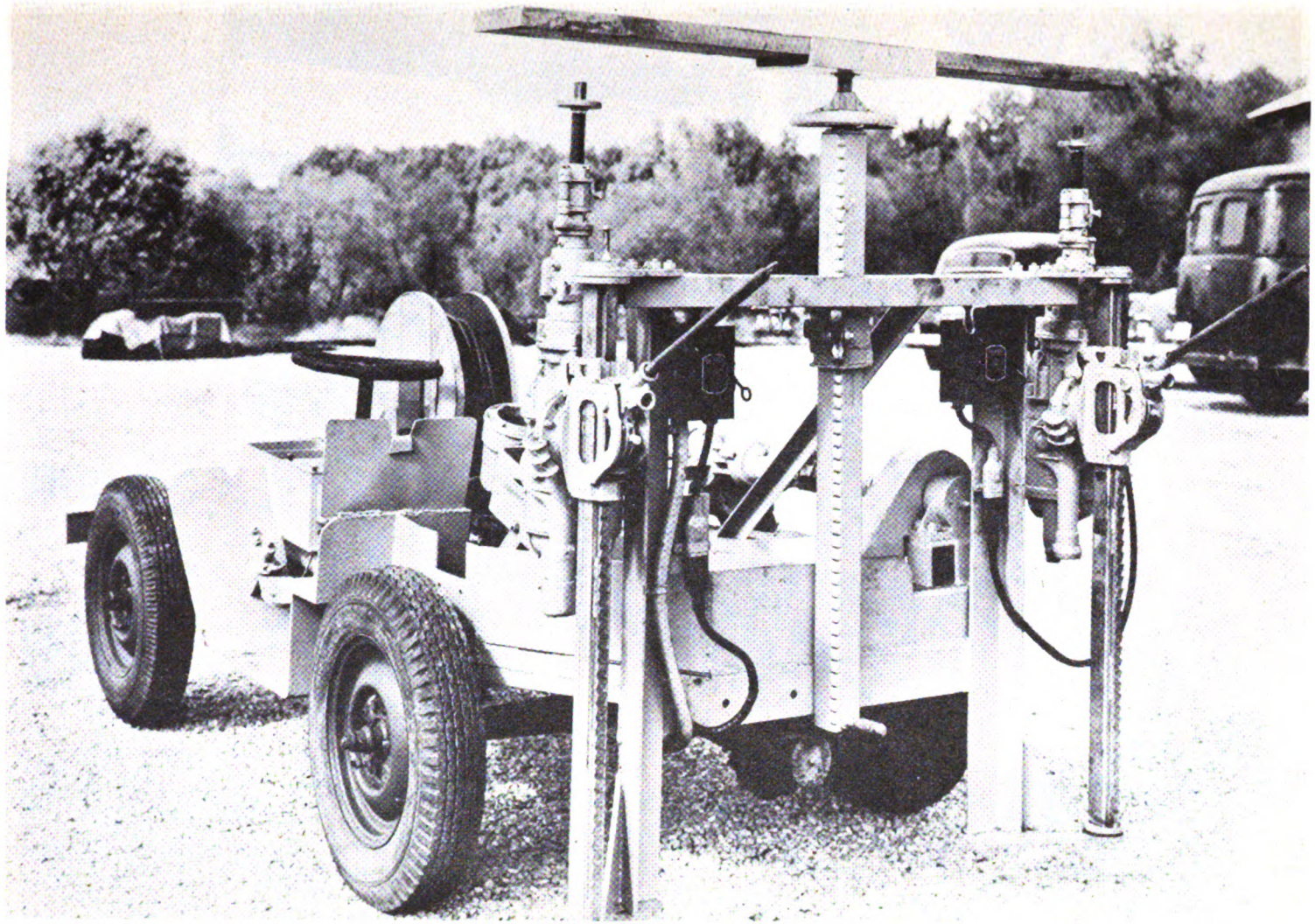

Figure 2. - Roof-bolt machine.

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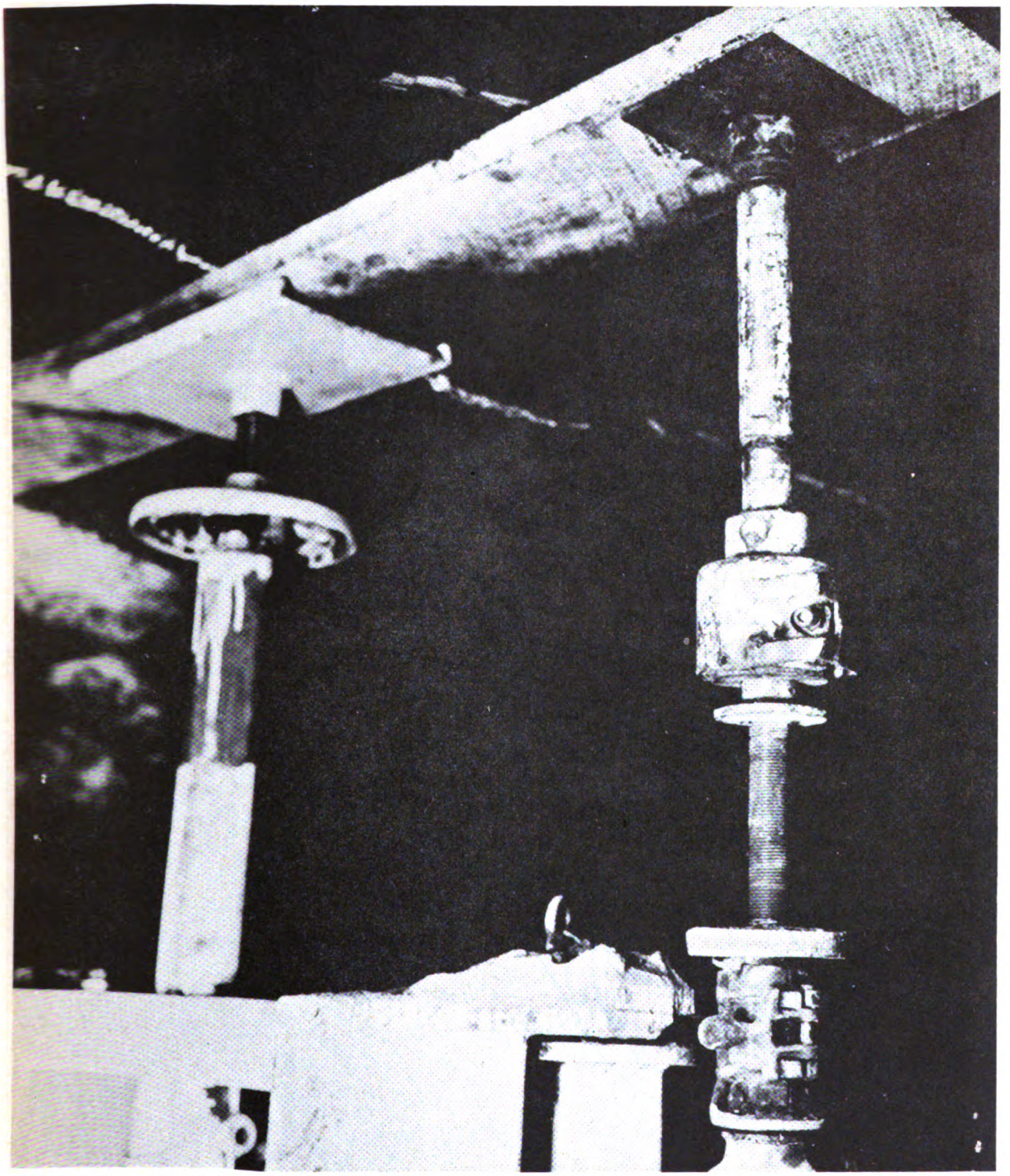

Figure 3. - Electric clutch wrench.

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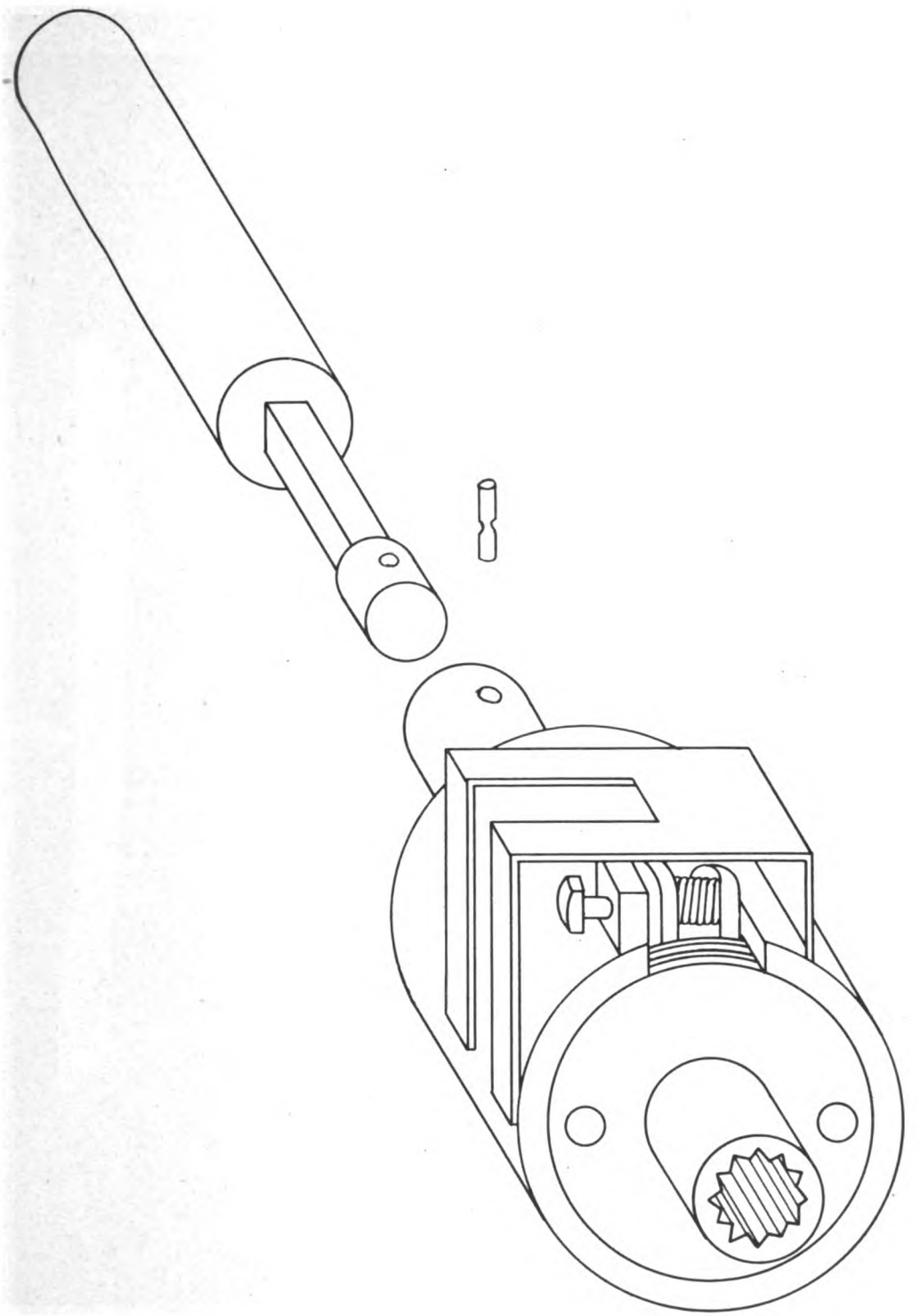

Figure 4. - Sketch of clutch wrench.

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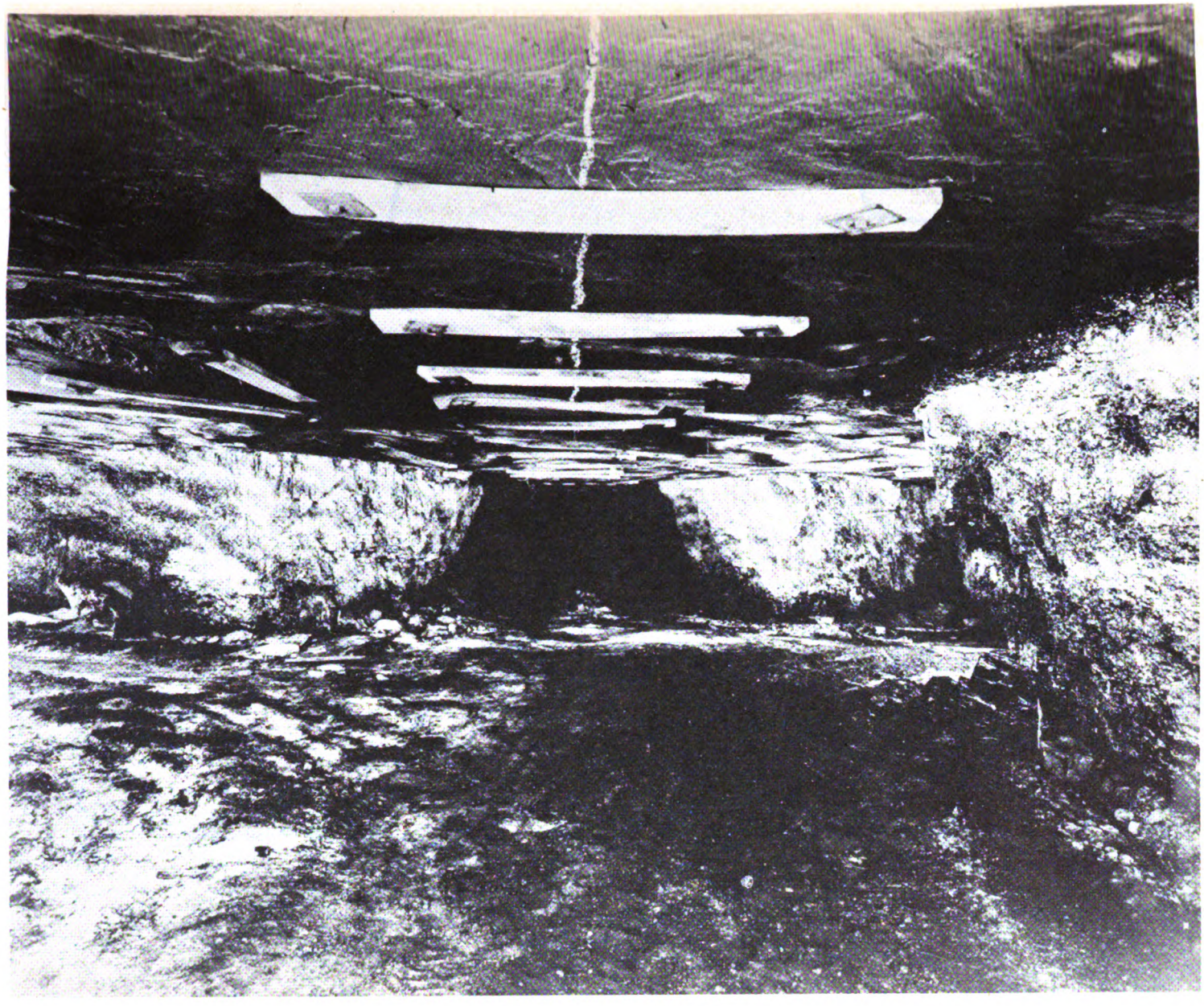

Figure 5. - Roof bolts installed in an entry.

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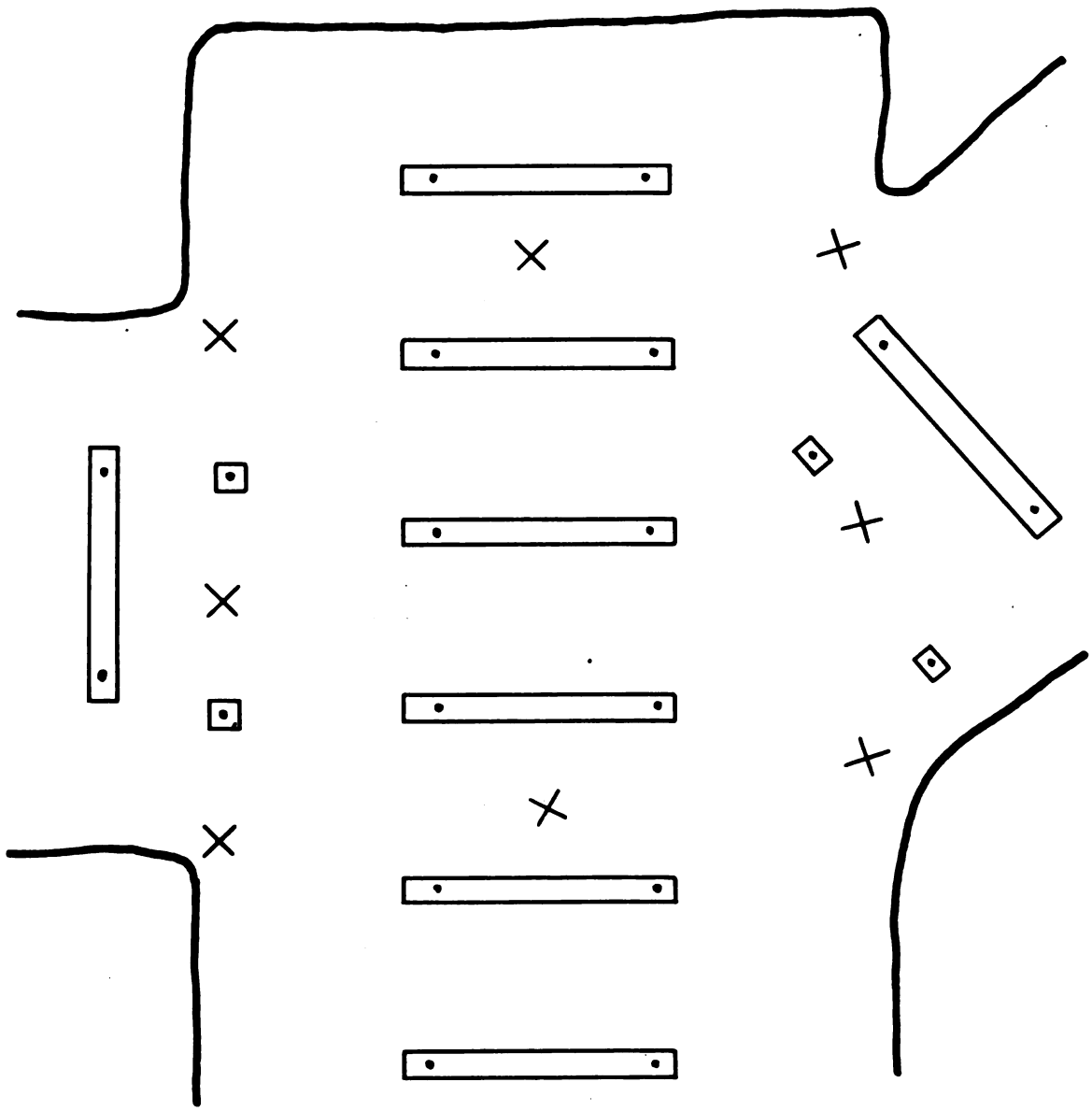

Figure 6. - Sketch showing location of cable hangers designated by x.

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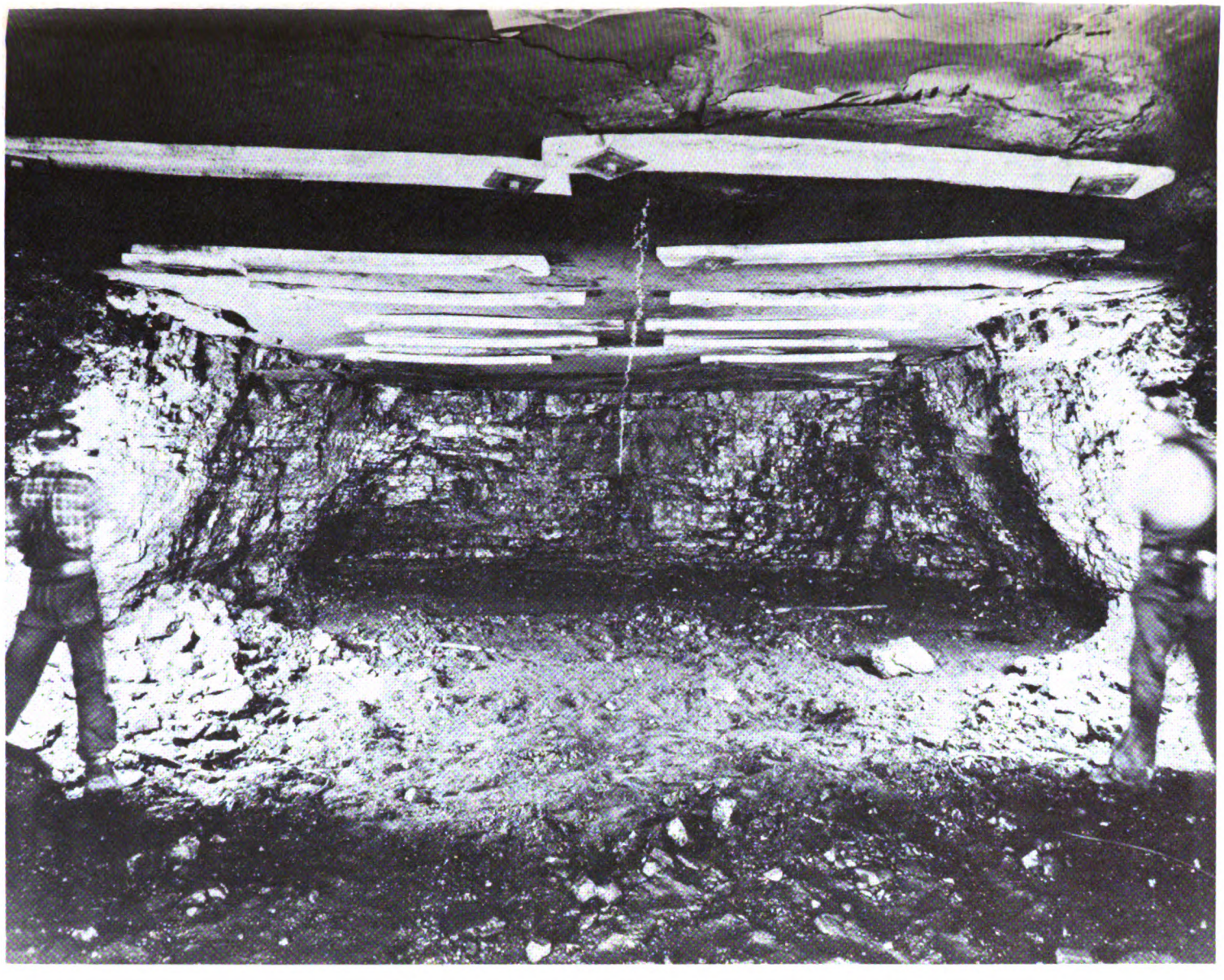

Figure 7. - Roof bolts installed in a room.

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METHOD OF INSTALLATION

Roof bolts are installed as soon as the loading machine leaves the place and before the mining machine enters. Two bolts with the plank are installed every 4 feet in the entries and four bolts with two planks are installed every 4 feet in the rooms. This is the minimum. In places where the roof appears to be doubtful, additional single bolts are installed, using oak slabs 1-1/2 by 8 by 16 inches for bearing plates. Steel plates 8 inches by 8 inches by 3/8 inch are used between the nuts and the slabs or planks, whichever the case may be. All of the bolts are 5 feet long.

When the bolting crew enters a place, the foreman takes the sights and has them mark the sight line on the roof. In the entries, the plank is centered on the jack and raised to the roof. The two holes are then drilled through the holes in the plank and the roof bolts installed. Figures 5 and 6 show the practices in the entries. In the rooms four bolts and two planks are used; the planks are equidistant from the sight line, as shown in figure 7. There is no deviation from this procedure, except where advisable because of the roof. To be sure that this pattern is adhered to, the following printed list of rules is given to each foreman:

RULES FOR FOREMEN USING ROOF BOLTS

1. Bolts must be installed properly, i.e., immediately after the place is cleaned up and before again undercutting.

2. Foremen must run the sights and have the roof bolters mark a continuous line on the roof. The time to do this is while the loading machine is moving and you have the roof bolters to help you.

3. After the sights have been taken, inspect the face carefully and mark the width of the place on the ribs. Test for loose ribs, face, and any scaling of the roof. Have the roof bolters take down any loose material immediately. DON'T TAKE CHANCES - NOW IS THE TIME TO DO IT.

4. Inspect the roof carefully. If any slips have shown up, determine the best places for additional roof bolts. Talk it over with the roof bolters and mark the spots for the additional roof bolts.

5. If the entry has advanced to a point where a crosscut is required, lay it off on the rib. Mark off and have 3 extra bolts installed on the rib line for extra support before the first cut is made in the crosscut. Remember that after this crosscut has advanced your roof area has increased and more roof support is required.

6. Inspect your roof bolts every cut. See that they are installed properly and that they are tight. Remember that you also work in these places.

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7. Be wary of slips and inspect them carefully. This will indicate the correct spots for additional bolts that are not required in normal places. REMEMBER THAT THESE SLIPS ARE YOUR ENEMY NO. 1.

8. Keep your cable hanger plan in mind. If the cable hangers are due to be installed, mark their locations on the roof. Have them installed before they are needed. This will save you cable delays and please your employees charged with keeping the cables in the clear.

9. Roof bolting allows you to keep from 6 to 8 inches of bottom coal for roadways. Always inspect this bottom coal on roadways. The time to do this is immediately after the loading machine leaves the place as your mining-machine men will be next to work in this place and you can show them regarding thin or thick bottoms. Remember one of your major delays has been from having the shuttle cars mired.

10. Making the foregoing rules your regular work pattern, will make your work easier. Do this immediately after the loading machine leaves the place. The roof bolters are there to help you take the sights. Remember that your employees have greater respect for the alert, safe foreman who is striving continuously to make them safe with a better place to work.

In addition to the above, it is the foreman's duty to inspect the bolts and the roof between each of the operations in the mining cycle, namely: Bolting, cutting, drilling, breaking, and loading.

RESULTS

Roof-Bolting Principle Applied to Support of Trailing Cables

During a study of the various delays in the mine each day, the officials noticed that those resulting from trailing-cable failures appeared to be excessive. Upon investigation, it was determined that most delays resulted from trailing cables being run over. To remove the cables from the floor at the entrances to crosscuts and rooms and other places where shuttle cars, mining machines, drills, and loading machines were working, it was decided to have the bolting crews install some means of cable support where crosscuts or rooms would be turned. Some 3-inch steel tubing was available, and the company officials decided to cut some of these tubes into 2-inch lengths, weld two of them together, and then weld a 4-inch-long bolt at the point of tangency of the tubes and the bolt head, as shown in figures 8 and 9. A 1-3/4-inch slot was then cut in each section of the tubing so that the cables could be inserted into the hanger. The bolt was equipped with a round expansion shell of the kind used for trolley hangers. When the roof bolters were advancing along the entry, they drilled three 4-inch holes at places where rooms or crosscuts would be turned in the normal course of mining and installed a cable hanger in each of these holes when they were installing the roof bolts, as shown in figure 6. Thus, when the rooms or crosscuts were turned off the entry, the cable hangers were in place ready for use. An illustration of their use is shown in figure 10.

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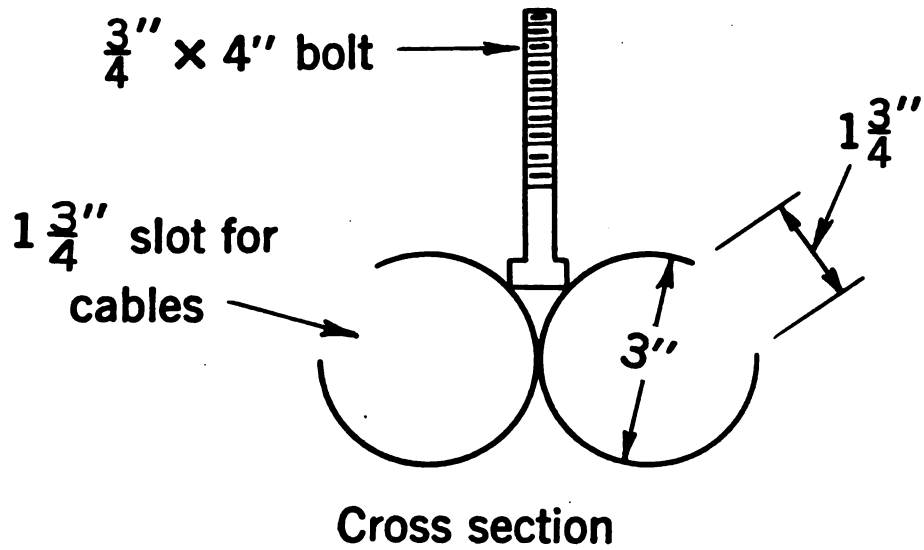

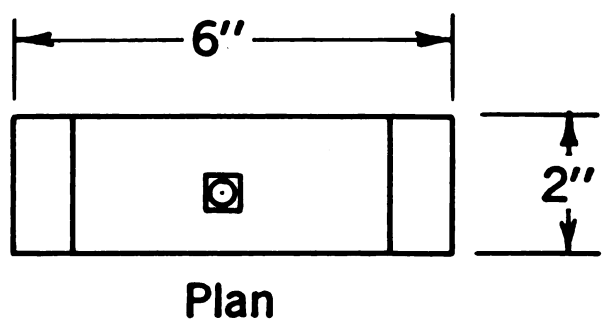

Figure 8. - Detail of cable hanger.

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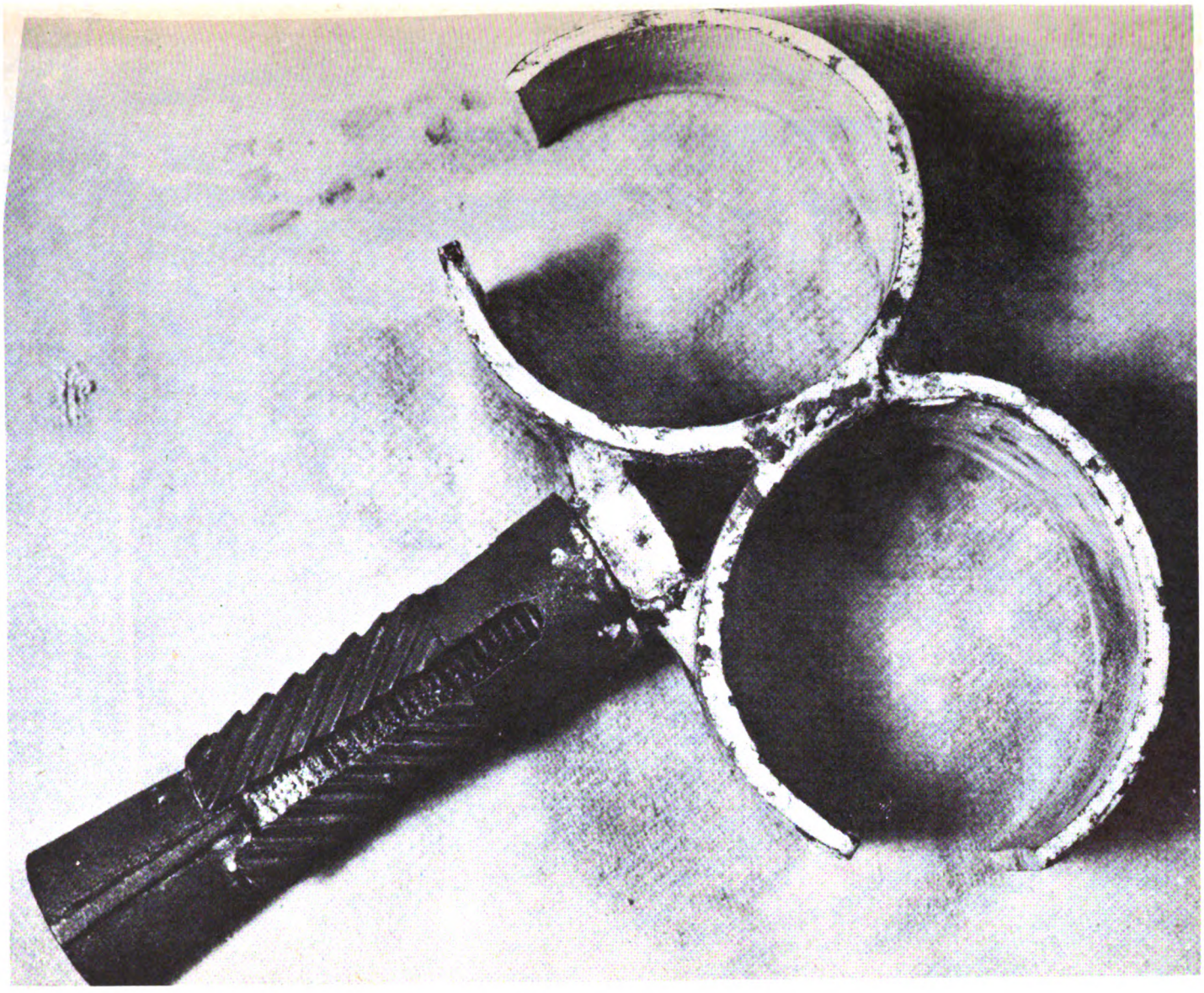

Figure 9. - Photograph of cable hanger.

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Figure 10. - Cable hangers in use.

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These cable hangers were used first in July 1951, and the following table shows a comparison of time lost because of cable failures for July, August, September, and October 1951. Approximately the same number of days were worked in each of the 4 months, hence the figures shown in table 1 are comparable.

TABLE 1. - Number of minutes lost in July, August, September, and October 1951, as result of trailing-cable delays in Zeigler No. 3 mine

Month	Delays in minutes	Remarks
July	1,900	Cable hangers not in use.
August	1,760	Use of cable hangers begun.
September	805	Use of cable hangers developing.
October	435	Do.

Note: An arbitrary value of 200 minutes a month was taken by the officials as the irreducible minimum for delays caused by trailing-cable failures.

Increased Tonnage Obtained Through Use of Roof Bolts

The Zeigler No. 3 mine was operated for approximately 2 years before roof bolting was adopted extensively. During this period, timbers consisting of cross bars and posts were used exclusively, and, owing to the exceptionally bad roof conditions, it was necessary to keep the timbering close to the faces. The mine was timbered conscientiously and efficiently in accordance with the company's established policy, but the work required to do it in this manner consumed so much time that it slowed the operations of cutting, drilling, breaking the coal, and loading. During this period, production at the face was approximately 16 tons per man-shift. Roof bolting was begun extensviely in the summer of 1951 and after 3 months operation under roof bolts, the tonnage per man-shift at the face had increased to 22.6 tons. This increase was due to a decrease in the time required to perform the work represented in the following factors: (1) Supporting the roof; (2) cleaning up falls and handling rock; and (3) the increased head room and clearance space for the various machines when posts and legs were removed. The increased tonnage per man-shift at the face after the adoption of roof bolts is shown in detail in table 2.

TABLE 2. - Tons per man-shift at faces in 4 months preceding use of roof bolts, as compared to tons per man-shift at faces after roof bolting was begun in Zeigler No. 3 mine

Before roof bolts were used, tons per man-shift at faces				After roof bolts were used, tons per man-shift at faces				Average percentage increase in production per man-shift
Unit	February	March	April	May	Second half of July	August	September	October	
5	14.65	14.90	15.93	16.63	22.26	24.23	23.77	26.05	54
6	15.62	16.70	17.12	17.61	22.43	23.92	23.41	25.55	42
11	17.67	17.69	18.79	19.63	19.63	14.91	19.81	22.50	4
12	17.12	18.01	19.12	19.71	18.97	17.18	21.56	25.80	13
13	14.78	14.34	14.79	15.50	21.16	25.94	26.04	25.92	61
14	No data	14.64	15.96	16.35	20.69	25.07	23.07	22.78	47

Notes: No data available for June.
Slight rise in May was due to the fact that some roof bolts were being used. Full program became effective in July.

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DISCUSSION

Experience in the coal fields of the Middle West has indicated that the success or failure of roof bolting in a given mine depends on two factors - one intangible and one tangible. The intangible factor is the question of confidence. If one or more officials of authority in the organization refuse to accept roof bolting, regardless of the experience in other mines or in their own mine, the roof-bolting program will not succeed. For success in the program, every one involved must have confidence in the method or an attitude open to acceptance of the results of fair trials. When the first experiments promise success, top and subordinate officials must continue without prejudice and also without overconfidence until a reliable plan is worked out. The higher officials should prove by careful experiment with which everyone in the organization is fully conversant that the adopted plan is safe and a benefit to all. This is what was done in the Zeigler No. 3 mine.

The tangible factor is system. This involves a predetermined pattern worked out through controlled experiments as to the number of bolts in a set, the length of the bolts, the distance between the sets, the marking of the center line, and the use of the proper-size bit on the last drill.

If the bolts are installed haphazardly or in places dictated by the judgment of individual underground officials or workers, failures may occur with a loss of life or property. The companies that are obtaining the maximum benefits from roof bolting are those that have incorporated roof bolting into the mining cycle systematically, that is, roof bolting, cutting, drilling, breaking down the coal, and loading. If this system is maintained, the roof at the face is secured, in most cases, in time to prevent appreciable sag of the roof beam, and the possibilities of ultimate success are enhanced. It has been found in at least one midwestern mine where roof bolts are recovered that, when the bolts were installed at the face, the roof remained intact for some time after the bolts were withdrawn, whereas in other localities in the mine where the bolts had been installed two or three cuts back from the face, the roof caved quickly after recovery of the bolts.

The practice of extending a marked center line on the roof with each cut, and then using it, insures that the bolts will be placed according to the predetermined pattern and relieves the roof bolter of the responsibility of guessing correct spacing of the bolts. Where members of the bolting crew are allowed to use their own judgment and locate the bolts in places where they think they are needed, it often happens that not enough bolts are used, with the consequent danger of unpredictable roof failures. The practice of using the center line in this mine has helped greatly in systematizing the roof-bolt installation.

In at least two instances in the Middle West, failures with expansion-shell roof bolts have occurred because the drillers were careless in their selection of bits to finish the holes to the correct diameter needed for proper seating of bolts. This same effect results from using bits that have been worn past allowable tolerances. The policy in this mine is for the driller to check his bit size at frequent intervals and, regardless of circumstances, if the bits are not the correct size, to stop drilling until the

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proper bits are secured. This requires workmen with a good sense of responsibility and proper supervision.

The value to the operator of the use of cable hangers in reducing delays in the working sections is obvious by a study of table 1. It is difficult to imagine a simpler way of increasing the daily tonnage and reducing costs than by adopting this means of keeping trailing cables from being run over by the various machines.

The increased tonnage per face worker shown in table 2 is characteristic of the results obtained by the use of roof bolts in very difficult roof conditions. The advantages of the increased tonnage and the consequent lowering of production costs are obvious and require no comment.

It is well to give a great deal of thought to the training of the men who drill the holes and install the bolts. It is obviously impossible for any supervisor to watch each hole drilled and each bolt installed, but he can test each bolt with a torque meter to see if it is installed properly. If the holes for any one bolt or group of bolts are bottomed in clay or any other soft material, the probabilities are that this bolt or bolts will pull out if any weight comes on them. The roof bolters are the only ones that know the condition of these holes because they can tell by the character of the drillings the sort of material they are in. If they install the bolts in clay or other soft material, they are creating a hazard for themselves or any others who may pass under them. When the roof bolters encounter this or a similar condition, they should stop work and send for the foreman, who should have the place made safe with conventional timbering. The roof bolters have been instructed in this procedure in the Zeigler No. 3 mine.

ACCIDENT RECORD

Even though the tonnage per man-shift has increased remarkably since roof bolting has been adopted, the officials consider that the greatest gain has been made in safety. The roof bolts are installed in the sections having the worst natural roof conditions in the mine, and, since they have been used, there has not been a lost-time accident as a result of roof falls in any of these sections. In 1950, the year before roof bolts were used, there were 10 lost-time accidents and 11 no-lost-time accidents as a result of falls of roof. The conclusions of the officials are that mining is safer and more efficient when roof bolts are used properly.

The results and conclusions presented in this paper were obtained by observing the practices in this mine, and the adoption of some of the practices described might well be beneficial in many other mines in using roof bolts.

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